Testing the Ability of the Willamette Basin Reservoir System to Meet Proposed Fish Flows

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Abstract

In July 2000, the National Marine Fisheries Service (NMFS) drafted a biological opinion for the Upper Willamette Basin, which is home to several threatened species (spring Chinook, winter Steelhead, and others). Included in the biological opinion was a recommendation that the U.S. Army Corps of Engineers (USACE) develop flow release strategies designed to benefit natural fish populations.

In cooperation and coordination with NMFS, Bonneville Power Administration (BPA), U.S. Bureau of Reclamation (USBR), U.S. Fish and Wildlife Service (USFWS), and the State of Oregon, USACE scripted target flow criteria for abundant, moderate, and low storage water years at locations on the Willamette mainstem.

The Portland District contacted the Hydrologic Engineering Center (HEC) for technical assistance with a reservoir analysis designed to answer one fundamental question: *Based on historical hydrology, could the Willamette Basin Reservoir System have released enough water to meet the new fisheries requirements (which called for flows and volumes as much as triple the original requirements)?*

An HEC-5 model, originally developed by the Portland District, was modified and calibrated for use in this study. For such a fundamental question, the application was actually quite complex with 10 storage reservoirs operating to meet high and low flow criteria at multiple downstream points over a 64-year period of record. This paper provides study background, presents technical results, and discusses how technical information was used in an interagency setting.

Introduction and Background

<u>Willamette Basin Project</u>. The Willamette Project consists of eleven storage lakes and two re-regulating dams, all located on tributary streams (Figure 1). These multipurpose projects share space for winter flood damage reduction and summer conservation storage. Combined, there are about 1,600,000 acre-feet of usable conservation storage. The flood season extends from mid-November through April; conservation use extends from May through mid-October and tends to be highest

during the seasonal drought, which usually occurs during August and September of each water year. Water control diagrams for Basin Reservoirs reflect this cycle. Allowable conservation storages drop in late summer and fall to minimum conservation pools (maximum flood pool), which are reached by November or December. These minimum limits are maintained through February and then begin to increase back towards maximum allowable conservation storages. Individual projects regulate tributary drainage areas that vary from 104 mi^2 to 991 mi^2. Total drainage area of the Willamette Basin is about 11,100 mi^2 at Portland, Oregon. The projects regulate approximately 27% of this total area.

Figure 1: The Willamette Basin and reservoir system.

Project Authorized Purposes. The Willamette Valley Project is authorized for flood damage reduction, irrigation, municipal/industrial, navigation, water quality, fish, wildlife, and recreation.

Study Instigation.

Endangered Species Act. Since the early 1990's several species of Willamette Basin fishes, mostly salmonids, have been listed as either threatened or endangered under the Endangered Species Act (ESA). These include Oregon Chub (endangered October 1993), Columbia River Bull Trout (threatened June 1998), Upper Willamette Spring Chinook Salmon (threatened March 1999), and Upper Willamette (Winter) Steelhead (threatened March 1999). Under ESA Section 7 Consultation, a review of issues affecting various fisheries was undertaken and recommendations were proposed to diminish the effects of Willamette Basin Project operations on these fisheries. These were consolidated in the Federal Review Draft 2001 Biological and Conference Opinion.

BiOp. In March 2001, NMFS and USFWS (jointly, the Services) provided preliminary drafts of a Federal Review Draft Biological and Conference Opinion (BiOp) discussing operation of the Willamette Basin Project to the Portland District, USACE, for review and comment (USACE et al. 2000). Ten Reasonable and Prudent Alternatives (RPA) to the "proposed action," which in this case was the status quo or "no-action" plan, were set forth for discussion. The second (RPA Nr. 2) recommended continuation of the spring and early summer mainstem minimum flow objectives (initiated in 1999), which were designed to improve salmon and steelhead migration by reducing the effects Willamette Reservoir operations have had on natural hydrographs.

In the Portland District response to the Services, concern was expressed that under drier than average conditions (as experienced in 2001), it would be impossible to implement the proposed flow objectives. Portland District staff agreed to develop a decision-making protocol and operational criteria for meeting the flow objectives across a range of hydrologic conditions. The initial step in developing the protocol and operational criteria was to evaluate the potential effects on project purposes.

Modeling Scheme and Input.

Flow Requirements. Starting in 2000, draft RPA Nr. 2 called for implementation of biologically based, weekly average and instantaneous minimum flows for the Willamette River at Salem, Oregon (Table 1). These biological flow objectives were formulated by Oregon Department of Fish and Wildlife (ODFW), adopted by the Services, and have been used by USACE to guide operations since 1999. Flow objectives during the first two weeks of May are based on a limited 'stock-recruitment versus flow' evaluation for the Willamette River at Salem (Mamoyak et al. 2000). For all other periods April through June, flow requirements are based on ratios of the historical natural hydrograph. These new objectives in no way replace the Congressionally authorized flow requirements (Table 2), which have been, and continue to be, an important operational consideration for Willamette Projects.

Table 1. Biological Minimum Flow Objectives for the Willamette River at Salem from April 1 to June 30 for an abundant storage year.

Time Period	Weekly Average Minimum Flow (cfs)	Instantaneous Minimum Flow (cfs)
April 1-15	20,500	16,500
April 16-30	17,800	14,300
May 1-31	15,000	12,000
June 1-15	13,000	10,500
June 16-30	8,700	7,000

Table 2. Congressionally Authorized Minimum Flow Objectives for the Willamette River at Salem and at Albany (extending September flow objective through 31 October).

Time Period	Average Flow at Albany (cfs)	Average Flow at Salem (cfs)
June 1-30	4,500	N/A
July 1-31	4,500	6,000
August 1-15	5,000	6,000
August 16-31	5,000	6,500
September 1-30	5,000	7,000
October 1-31	5,000	7,000

Model. The reservoir simulation software selected for use was *HEC-5: Simulation of Flood Control and Conservation Systems*. HEC-5, a computer program first developed and distributed in 1973 was designed by the Hydrologic Engineering Center (HEC) to offer guidance in real-time reservoir release decisions and to aid in planning studies for proposed reservoirs, operation alternatives, and flood space allocation. The program is designed to accept criteria related to flood operations, hydropower generation, river routings, diversions, and low-flow operations. Simulations can be performed a variety of time steps ranging from 5 minutes to monthly. HEC-5 is a USACE standard tool in reservoir analyses.

Data. Daily time series of reservoir inflows from headwater watersheds, inflows from watershed areas between reservoirs in series, and local flows (flows from watershed areas below the dam sites) were prepared by the Portland District. A complete set of these data, 1936-1999, was used as input to the reservoir system model.

System Analysis Procedure and Results

The Portland District contacted the Hydrologic Engineering Center (HEC) for technical assistance with a reservoir analysis designed to test the ability of Willamette Basin reservoirs to meet the new BiOp flow requirements.

The HEC-5 model to be used in this work was originally developed in 1990 by NWP as a monthly simulation model to investigate water conservation. In 1995, the simulation time step was changed to daily in support of a feasibility study of system operations. Throughout its life, the model has been modified to best serve NWP and needed to be calibrated for use in this particular project. A series of tests of the model under BiOp criteria was performed by NWP. The district reached an impasse in the application of HEC-5 due to the complexity and the particular configuration of the BiOp requirements and contacted HEC staff for advice and technical support.

The purpose of this model application is to determine if the BiOp flows can be met reliably and to quantify the reservoir impacts that result. This section documents 1) study procedures, 2) HEC-5 input model modifications and application, and 3) simulation results of the HEC-5 model used during analysis of the BiOp flows. Conclusions of this cooperative effort between NWP and HEC will provide input to the draft Willamette biological opinion prepared by NMFS.

This section is formatted as the series of tasks (and the results thereof) used to assess the ability of Willamette Reservoirs to meet BiOp flow requirements. For a more thorough study background and definition of terms, readers are encouraged to review Duffe et al. 2003.

<u>Task 1. Construction of the baseline HEC-5 model</u>

This task focused on input model modifications designed to assure that downstream flow requirements would be met logically and efficiently during simulations. Several changes to the HEC-5 model provided by NWP were incorporated into the baseline model (USACE 2002). While some were minor (even cosmetic), the following involved significant changes in modeling strategy and results:

- <u>Only Lookout Point, Green Peter, and Detroit operate directly to meet Salem BiOp flow requirements</u>. HEC-5 computational routines schedule releases to meet flow requirements shared by multiple reservoirs in a way that seeks to balance the reservoir levels of those facilities.

  With all reservoirs operating for Salem (as simulated in the NWP model), smaller reservoirs would become prioritized to meet downstream requirements whenever their levels were the highest. In response, these facilities would release as much as possible given other constraints (e.g., outlet capacities and intermediate channel capacities between the dam and Salem). The effects of these small reservoirs "switching on" for Salem requirements were three-fold. First, small reservoirs were incapable of releasing enough flow to meet the significant flow requirements at Salem. Second, when small reservoirs were "switched on," the large reservoirs (Lookout Point, Green Peter, and Detroit) reduced releases by more than the flow added from smaller reservoirs. And third, increased releases from small reservoirs would quickly reduce reservoir levels in those facilities because of the relatively small storage capacities of those pools, which led to a "switch on – switch off" toggling that complicated release scheduling. All of these dynamics disrupted releases of water to meet Salem, which led to shortages at Salem and inconsistent reservoir releases despite having storage adequate to meet system requirements.

• Use 5 Reservoir Levels instead of 10. The 10 level scheme in the NWP model was designed to prioritize the drafting of Willamette Reservoirs, but further complicated the scheduling problems mentioned above and encouraged the "switch on – switch off" dynamic. Use of 5 levels simplified the model and enhanced compliance with Salem requirements.

• All routings removed from model. As the purpose of this modeling effort was to determine whether BiOp flows requirements can be met reliably, the critical question is whether system storage is adequate. Since routing is not central to the question and could complicate the analysis, it was removed from the model.

• Foster Reservoir removed from model. Foster is a small reservoir (24,830 ac-ft maximum conservation space) located downstream of Green Peter Reservoir on the Middle Fork of the Santiam River. In terms of storage, Foster plays a minor role in the Willamette Basin. However, in HEC-5, due to its location between Green Peter (one of the largest reservoirs in the Basin) and the Salem operating point, Foster disrupted operation of Lookout Point, Green Peter, and Detroit Reservoirs as those facilities scheduled jointly to meet flow requirements at Salem. Because its significance with regards to basin operations did not justify its effects in the simulation model, Foster was removed.

• Releases from smaller facilities based on the reservoir level of Lookout Point. The presence of large and small reservoirs in level-based release scheduling for Salem requirements led to errant shortages at Salem (see first bullet in this section). To improve model simulations, operations of Hills Creek, Fall Creek, Cottage Grove, Dorena, Cougar, and Blue River Reservoirs were altered such that they did not operate explicitly for Salem in the HEC-5 model. Instead, seasonal flow requirements were added that computed reservoir releases (for all of these facilities) based on the concurrent reservoir level of Lookout Point.

The strategy follows that as Lookout Point uses storage (level declines) to meet the Salem requirements, releases at the smaller reservoirs (or those upstream of a larger facility) increase proportionally. This takes some of the burden off of Lookout Point, Green Peter, and Detroit Reservoirs (who operate explicitly for Salem) without complicating the scheduling.

A weakness of this strategy is that the smaller reservoirs are indeed blind to Salem; there may be instances when the level in Lookout Point is low and, accordingly, the smaller reservoirs maintain high releases with no shortage at Salem.

Task 2. Period of record simulation and sorting of individual years according to Net System Storage

After the baseline model had been finalized, it was used to perform a simulation of the 64-year period of record (1936-1999). This simulation included BiOp flows requirements at Salem for abundant volume years regardless of year type (Figure 2). Each simulation year in the period of record began on January 1 with all reservoirs at minimum flood pool (all conservation space full; all flood space empty). Again, for complete definition of BiOp flows and volume types, readers are referred to USACE 2002.

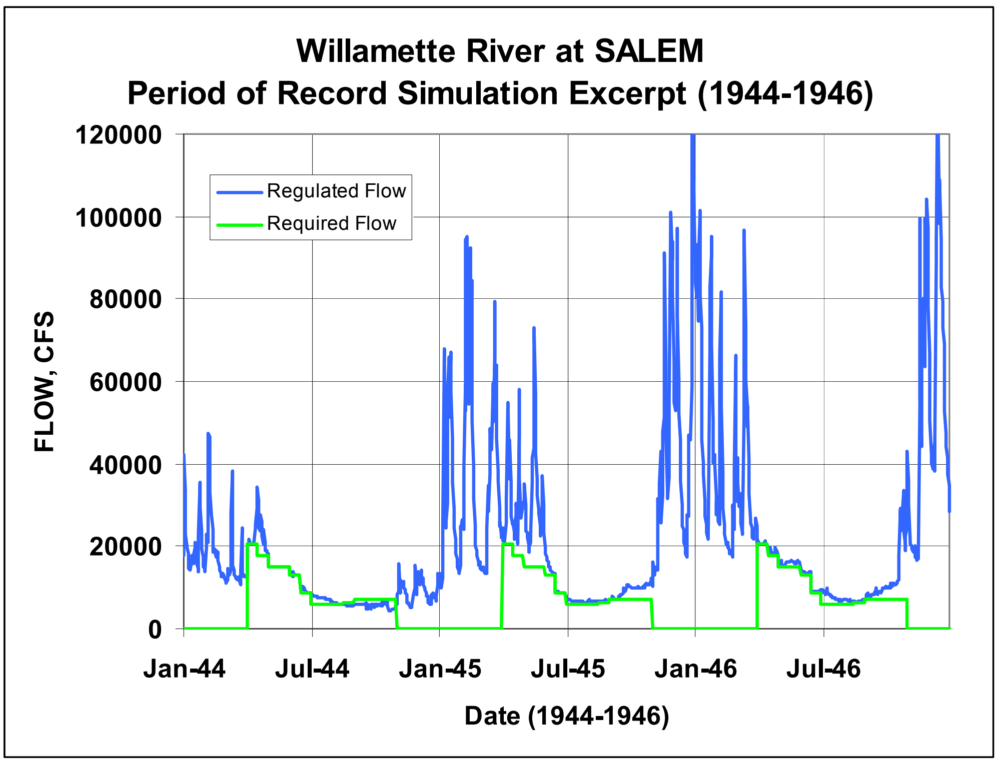

Figure 2. Excerpt of baseline period of record simulation results for regulated flows at Salem. Required flows used in simulations were held constant from year to year regardless of volume-type.

Using the period of record results, simulated storages for all modeled reservoirs were summed for each day of the year. To compute Net System Storage, the combined inactive storage of all reservoirs was subtracted from the time series of summed storage (for each day). The maximum Net System Storage between May 10 and May 20 (May 15 ± 5-days) was then used to classify each year as abundant (>1.48 million acre feet (MAF) net storage), low (<1.20 MAF net storage), or moderate (between or equal to 1.48 and 1.20 MAF).

Sorting classified 37 of the 64 years of record as abundant, 11 as moderate, and 16 as low volume-type years (Figure 3). These years were then simulated individually with BiOp requirements tailored to their volume-types and Net System Storages.

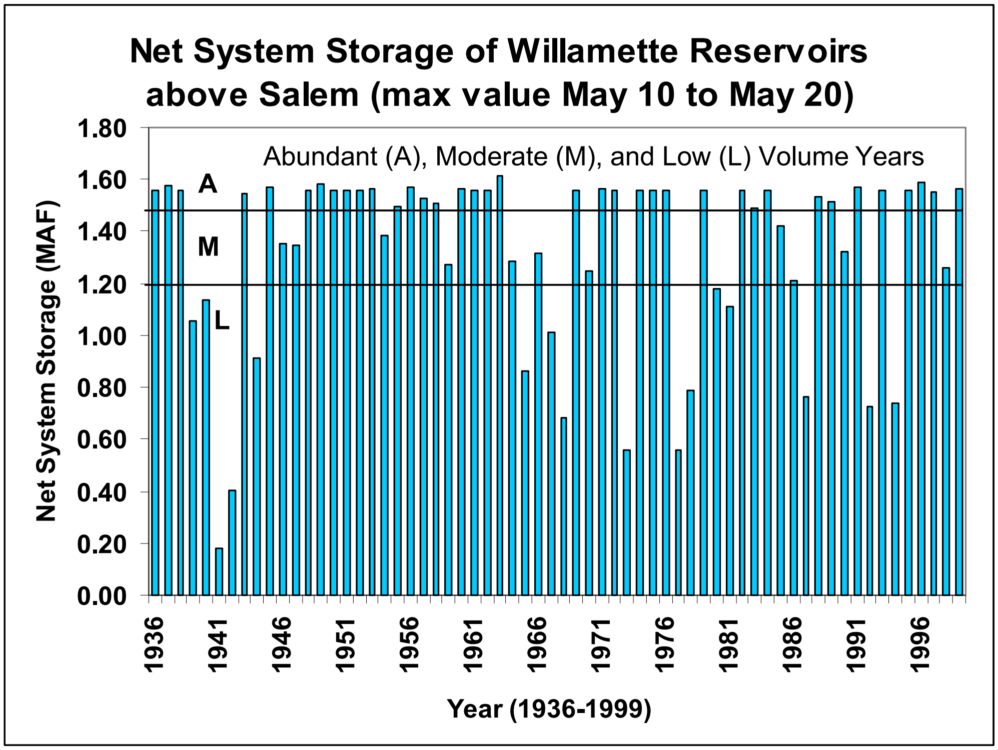

Figure 3. Plot of maximum Net System Storage between May 10 and May 20 of each year. Maximum values were then used to classify each year as abundant (>1.48 MAF net storage), low (<1.20 MAF net storage), or moderate (between or equal to 1.48 and 1.20 MAF).

Task 3. Add BiOp flow operations (for each volume-type) to HEC-5 models and simulate the sorted water years with volume-type criteria individually

Replicate baseline models were developed for each year of the period of record. Baseline flow requirements at Salem and Albany were then replaced by year specific requirements in accordance with each particular year's volume classification (abundant, moderate, or low) and corresponding maximum Net System Storage. Methods for computing these year specific requirements varied according to volume-type and location and are documented in USACE 2002. All models began simulation on a start date of January 1 with all reservoirs at minimum flood pool.

Figure 4 shows an excerpt from the individual year simulations. Results were later assessed statistically to determine how reliably volume-type requirements could have been met during the period of record.

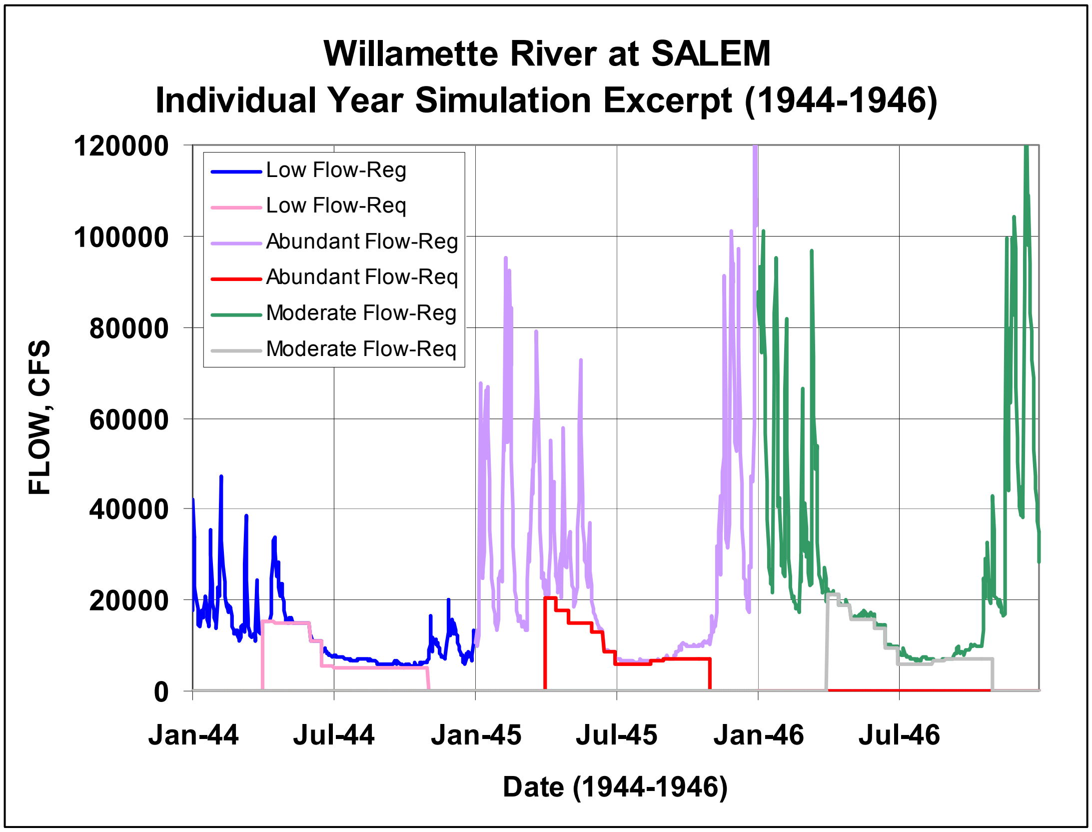

Figure 4. Excerpt (1944-1946) of individual year simulation results for regulated flows at Salem. Required flows used in simulations were varied in accordance with each particular year's volume classification (abundant, moderate, or low) and corresponding maximum Net System Storage. Plot contains a low volume (1944), abundant volume (1945), and moderate volume year (1946).

Task 4. Statistical analysis of the individual simulations

Results from the individual water year simulations were analyzed to determine the 1) percentage of years Willamette Reservoirs were able to meet BiOp flow requirements, 2) range and distribution of reservoir storages and water surface elevations throughout the year, 3) flow distributions at Salem, Albany, and reservoir outflows. The rest of this section focuses on the ability of the Willamette Reservoir System to meet the BiOp flow requirements. All other results, including an analysis of storage in Detroit Reservoir and comparisons of monthly simulated and unregulated flows, are available in USACE 2002.

BiOp flow requirements. Simulation results were inspected visually to determine whether system storage was adequate to meet the BiOp requirements. Periods of shortage (system storage deficient to meet requirements) were identified and are listed in Table 3. Table 4 lists the percentage of years able to meet BiOp (April through June) and Congressionally authorized (July through October) flow requirements.

Table 3a: Dates of shortage at Salem.

SALEM BiOp Flow Shortages								
Year	Category	April	May	June	July	Aug.	Sept.	Oct.
1940	Low					13-31	1-27, 29-30	1-23, 27-28
1941	Low	13-30	1-4, 9-17, 20-31	1-15	19-31	1-31	1, 8-10, 28-30	1, 3
1992	Low			1, 10-15, 26-27	25-31	1-31	1-24, 26-30	1-29
1994	Low	18-27			27-31	1-31	1-30	1-14, 17-26

Table 3b: Dates of shortage at Albany.

ALBANY BiOp Flow Shortages								
Year	Category	April	May	June	July	Aug.	Sept.	Oct.
1940	Low					13-31	1-27, 29-30	1-23, 26-28
1941	Low				19-31	1-31	1, 8-10, 17-18, 23-30	1-3
1973	Low					14-24, 26-30	1-6, 8-19	2-9
1987	Low						27-30	1-31
1992	Low				25-31	1-31	1-24, 26-30	1-20, 23-28
1994	Low					26-31	1-24, 26-30	1-20, 23-28

Table 4a. Volume-type ability to meet downstream flow requirements.

	Low (16 years)		Moderate (11 years)		Abundant (37 years)	
	Successes	Failures	Successes	Failures	Successes	Failures
Salem						
April to June (BiOp)	13	3	11	0	37	0
July to October (Cong Auth)	12	4	11	0	37	0
Albany						
July to October	10	6	11	0	37	0

Table 4b. Summary of all years ability to meet downstream flow requirements.

	All years (64 years)		
	Successes	Failures	% Success
Salem			
April to June (BiOp)	61	3	95
July to October (Cong Auth)	60	4	94
Albany			
July to October	58	6	91

Discussion of Systems Analysis Results

This model application focused on the efficient use of reservoir storage to meet downstream flow requirements. And if only the ability of system storage to meet BiOp flows is considered (water quality, water temperature, and recreation concerns of reservoirs and river reaches downstream of dam sites not addressed explicitly), simulation results and statistical analyses indicate that the Willamette Reservoir System is capable of meeting BiOp requirements in all but the driest years. In fact, no system deficiencies were identified during abundant or moderate volume years and the majority (75% at Salem and 63% at Albany) of low volume years were able to meet requirements.

The baseline HEC-5 model performed nicely during simulations of individual years with volume-type operations and does an excellent job using system storage to meet BiOp flow requirements. In fact, often, and for extended durations, simulated releases generate regulated flows identical to the flow requirements. This trend is especially evident in moderate and low years when natural flows are reduced and flow requirements are more dependent on reservoir releases. While this accuracy generates confidence in statistical results, simulations may do unrealistically well in terms of storage release efficiency to meet flow requirements. HEC suggests that if real-time operations tend to release waters that accumulate at Salem in excess of the required flows, the percentage of excess should be quantified and the BiOp requirements used in simulations adjusted accordingly. Simulations and statistical analyses should be repeated with these heightened flow requirements to determine if any potential shortages were masked by the accuracy of the baseline model.

Conclusions

As required by Congressional authorities, USACE has traditionally managed the Willamette Project to meet multiple responsibilities, including flood damage reduction, power production, pollution abatement, recreation, irrigation, municipal and industrial water supply, navigation, and conservation of fish and wildlife. The Biological Opinion adds an additional responsibility in accordance with the Federal ESA. In making operational decisions to meet ESA requirements, action agencies must take all appropriate measures within their authorities to protect the listed species addressed by the opinion. In some years, water resources will be insufficient to completely meet all traditional, as well as new ESA, responsibilities for the Willamette Valley Project.

The operational flow targets determined through the collaborative process described above and the associated flow management guidelines are intended to *balance* the risks to listed fish species under low water year conditions with the risks to other uses authorized by the U.S. Congress for the Willamette Valley Project. Key among these authorized uses are those significant to human health and safety concerns. These include hydropower production for use within the Willamette Basin and summer and fall low flow augmentation for maintenance of local water supply and water quality.

The Portland District Corps of Engineers, as a result of the Willamette Basin HEC-5 modeling work, determined that the overall project effects of implementing the proposed minimum biological threshold flows were "acceptable" based on historical and current level of water use.

In October 2002, results of the HEC-5 modeling and a NWP proposal based on the BiOp system evaluation were presented to the Services. The Services accepted the technical information presented and are making final modifications to the Reasonable and Prudent Alternative Nr. 2 in the Biological Opinion. The HEC-5 modeling, in conjunction with biological evaluations, was instrumental in developing a jointly acceptable adaptive approach to long-term management of the Willamette Basin System.

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